EXTERNAL COULOMB AND ANGULAR MOMENTUM INFLUENCE ON ISOTOPE COMPOSITION OF NUCLEAR FRAGMENTS.

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The Markov chain statistical multifragmentation model predicts inhomogeneous distributions of fragments and their isospin in the freeze-out volume caused by an angular momentum and external long-range Coulomb field. These effects can take place in peripheral nucleus-nucleus collisions at intermediate energies and lead to neutron-rich isotopes produced in the midrapidity kinematic region of the reactions.

Studies of multifragmentation phenomenon in heavy–ion reactions at high energies are very promising because of overlapping nuclear physics with universal physical processes taking place in finite particle systems. In particular, nuclear equations of state and phase transitions can be established [1]. As other complicated many-body processes this phenomenon can be successfully treated in statistical way [2,3]: Fragment production in both peripheral and central collisions has clear statistical features [2,4,5], though a considerable preequilibrium emission and collective energy (radial flow) should be taken into account. In finite-size nuclear systems statistical processes can lead to unusual effects since the fragment formation is governed by both short-range nuclear forces and long-range Coulomb forces. For example, a Coulomb interaction of the target and projectile-like sources leads to a predominant midrapidity ("neck"-like) emission of intermediate mass fragments (IMF, charges Z=3–20) [6]. In this contribution I show that a statistical process can also provide a non-isotropic fragment isospin production in peripheral nucleus–nucleus collisions.

The statistical multifragmentation model (SMM) is described in detail in many publications [2]. The model is based upon the assumption of statistical equilibrium at a low-density freeze-out stage. All possible break-up channels (partitions into fragments) are considered with weights defined by the entropies of the channels which depend on excitation energy E_s^*, mass number A_s, charge Z_s and other parameters of the source. After break-up of the nuclear source the fragments propagate independently in their mutual Coulomb fields and undergo secondary decays. The new version of SMM version is based on producing the Markov chain of partitions which exactly characterize the whole partition ensemble [7]. In a special way individual partitions are generated and selected into the chain by applying the Metropolis receipt [7,8]. Within this method primary hot fragments can be placed directly into the freeze-out volume to calculate their Coulomb interaction and moment of inertia. In this way one can take into account the correlations between positions of the primary fragments and their Coulomb energy that influences the partition probabilities. Angular momentum conservation can be included within this method similar to Refs.[3,9]. The full analysis of the Markov chain SMM appears somewhere [8].

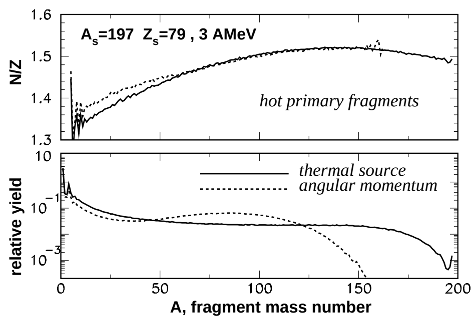

Figure 1: The neutron-to-proton ratio N/Z and relative yield of hot primary fragments produced in the freeze-out after break-up of Au nucleus. Solid lines: Markov chain SMM calculations for a thermal source with excitation energy 3 MeV/nucleon, dashed lines: the same source with angular momentum 150$\hbar$.

An angular momentum influence on isospin of fragments emitted from a single source is instructive. In Fig. 1 I show yields and neutron–to–proton (N/Z) ratios of hot primary fragments produced in the freeze-out volume (the density is ρ_s=ρ_0/6, ρ_0 is normal nuclear density) after break-up of Au source (A_s=197, Z_s=79) at E_s^*=3 MeV/nucleon. It is seen that an angular momentum favors fission-like fragment partitions with two large equal-size fragments (see also Refs.[3,9]). That is different from a normal fragmentation pattern dominated by partitions with different-size fragments. An angular momentum leads to increasing N/Z ratio of IMF also. The last effect is important and has a simple qualitative explanation: An angular momentum favors emission of IMF with larger mass numbers since the system in the freeze-out needs to have a large moment of inertia in oder to minimize rotational energy and maximize the entropy. From another side a Coulomb interaction prevents to emit IMF with large charge Z. As a result of interplay of these two factors we obtain the increasing of the N/Z ratio.

In peripheral nucleus–nucleus collisions at the projectile energies of 10–100 MeV/nucleon a break-up of highly excited projectiles-like nuclei is fast (the characteristic time is around 100 fm/c) and happens in the vicinity of the target-like nuclei. The influence of the Coulomb field of the target nucleus on fragmentation of the projectile source increases charge asymmetry of produced fragments and leads to non-isotropic fragments emission: small fragments are preferably emitted to the side of the target [6]. Within the Markov chain SMM one can study how this effect influences the isotope composition of fragments.

Calculations were performed for the same Au source as in Fig. 1. The source was placed at a fixed distance (20 fm) from another Au source. This distance was obtained under assumption that the break-up happens in $\sim$100 fm/c after a peripheral collision of 35 A·MeV projectile Au with target Au. It is naturally to expect the decays happen at different distances, excitation energies and angular momenta. In statistical approach we can take into account a distribution of the sources in distances and other characteristics by considering an *ensemble* of the sources. Parameters of this ensemble can be found by global comparison with the experiment [2,10]. However, the present approximation of a fixed distance is sufficient for qualitative identification of new statistical effects.

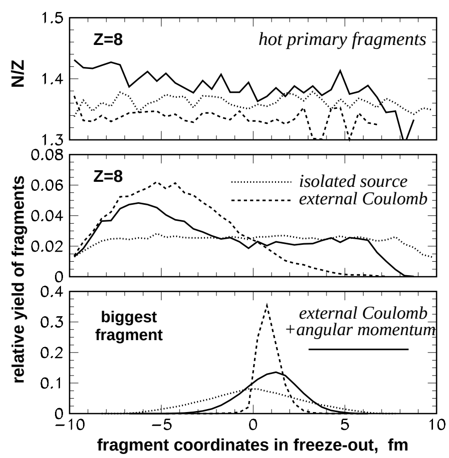

Figure 2: Freeze-out volume coordinate distributions of neutron-to-proton ratio N/Z of primary fragments with Z=8 (top panel) and relative yields of the primary Z=8 and biggest fragments (middle and bottom panels) produced at break-up of Au source at excitation energy 3 MeV/nucleon. The second Au nucleus is placed at -20 *fm* from the center of the freeze-out. Dotted lines: the isolated Au source, dashed lines: Coulomb influence of the second Au is included, solid lines: angular momentum 150 $\hbar$ is included additionally.

In Fig. 2 I show distributions of yields and N/Z ratio for hot primary IMF with Z=8 and the biggest fragments in the freeze-out volume along the axis connecting the projectile and target sources. It is seen that in case of a single isolated source all distributions in the freeze-out are symmetric respective to the center mass of the source. In case of the target Coulomb influence the IMF are mainly produced closer to the target while the biggest fragments are shifted to the opposite direction. These locations of fragments provide minimum of Coulomb energy in the target-projectile system. However, the external Coulomb alone influences hardly the fragment isospin distribution. In case of angular momentum the N/Z ratio of the IMF increases considerably and becomes larger when the IMF are closer to the target. The reason is again an interplay of the Coulomb and rotational energy: The system needs more heavy IMF to have a large moment of inertia while the Coulomb energy of the system depends also on IMF distance from the target and this energy is lower when the IMF charge is small.

This asymmetry of the IMF isospin distribution survives after secondary deexcitation of hot fragments. The following Coulomb propagation push the IMF in the direction of the target providing predominant population of the midrapidity kinematic region by neutron-rich fragments. The Coulomb repulsion may be not sufficient to accelerate fragments up to high energy, however, it can fill with the fragments a considerable part of the midrapidity region [6]. Within the statistical picture a slight radial flow can supply the IMF with high velocities to populate the center of the midrapidity zone.

In conclusion, it was shown that in peripheral nucleus–nucleus collisions characteristics of statistically produced fragments depend on Coulomb interaction between the target- and projectile-like sources and an angular momentum transferred to the sources. In particular, it leads to space asymmetry of both fragment emission and their isotope composition respective to the sources. Previously the symmetry violation was considered as a sign of a dynamical "neck" emission. However, there is an alternative statistical explanation: the symmetry of the phase space is deformed under interaction of the two sources. Theoretically such a process gives an example of a new kind of statistical phenomenon influenced by an inhomogeneous external long–range field [6].

References

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